OTKA PD-115451

FINAL REPORT
1 February 2016 – 31 January 2019

Studying the polarotaxis of aquatic arthropods and complex optical ecological traps in the aspect of conservation biology

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Summary

During the three years of the grant period I have built a couple of experimental equipment, which were utilized in field and laboratory experiments. Our results have been published in 6 English papers, 2 Hungarian popular science articles, 12 lectures and 2 posters. Further 3 manuscripts are under review/revision and 1 additional paper has also been published outside the topic of this grant. I am grateful for the support of NKFIH.

Achievements and Results

<u>(1) Polarotaxis of *Podura aquatica*:</u> I studied the polarization sensitivity of the water springtail (*Podura aquatica*) in a series of laboratory choice experiments, because polarization vision has not been studied before in springtails. The experimental apparatus was a custom-built arena with two light stimuli with variable polarization characteristics. The movement of the tested animals could be recorded with a camera, thus their attraction to differently polarized light stimuli could be quantified. Tens of thousands of *Podura aquatica* specimens were tested and we concluded that this species possess positive polarotaxis to horizontally polarized light. The results have been published [A1, B2, C3, C4, C9]. As far as we know *P. aquatica* is still the only springtail which has been shown to have the ability of polarization vision.

As a continuation, I designed new experiments for *P. aquatica*. To test the photo- and polarotactic behaviour of the water springtail as a function of wavelength I have performed a series of new laboratory experiments. With a custom-built light source being able to emit quasi-monochromatic lights of 14 different wavelengths with various light intensities, we showed that the polarization sensitivity of *P. aquatica* operates in the blue spectral range, but longer, green-yellow wavelengths are also important for this species. The manuscript is now under revision [A8].

<u>(2) Polarotaxis of two mayfly species:</u> Applying horizontally polarized, vertically polarized and unpolarized light traps and light sources, we studied the polarotactic behaviour of two mayfly species, *Caenis robusta* and *Ephoron virgo*. Both species swarm above water surfaces and it is essential for them to stay above the water. We showed that the attraction of these insects to

polarized light strongly depends on the polarization characteristics of the light stimulus. We found that the most, moderately and least attractive light stimuli were horizontally polarized, unpolarized, and vertically polarized. Skylight reflected from open waters are usually horizontally polarized, while light reflected from the water surfaces close to the shore are often unpolarized or weakly vertically polarized because of the mirror image of riparian vegetation. Based on our results and imaging polarimetric measurements of the habitats of these mayfies we concluded that both the strong and weak attraction to horizontally and vertically polarized light serve the stability of their swarming, and optically help these insects to keep their position above the water during swarming. The results have been published [A2].

(3) Polarized light pollution of matte solar panels: Solar panels are sources of polarized light pollution when they reflect horizontally polarized light. Recently a new, anti-reflective matte looking coating has been developed for solar panels, which is able to increase the efficiency by guiding more photons to the solar panel. Since matte surfaces generally reflect light with lower degree of polarization compared to shiny surfaces, it is a plausible assumption that matte solar panels are less attractive for polarotactic insects. In field choice experiments we tested whether this kind of matte coating reduces the attractiveness of solar panels to polarotactic mayflies, horseflies and nonbiting midges. We showed that the anti-reflective coating can reduce the attractiveness, but in some cases it becomes more attracive for mayflies, for example. The results have been published [A3].

(4) Ecological trap of *Ephemera danica*: Years ago at Bükkös-creek, we have observed that during their compensatory flight, *Ephemera danica* mayflies easily become off the track of the creek if they encounter a bridge overarching the water-course, and continue their flight above the road surface. We decided to test if it was only an impression or a real phenomenon. We deployed polarizing insect traps on the road at different distances from the bridge. The traps captured *E. danica* mayflies and their catch numbers indicated that these mayflies originated from the direction of the bridge, proving that they followed the track of the road. At another site, 3.2 km from a bridge overarching river Ipoly we observed *Ephemera vulgata* mayflies flying above and following the road. In field experiments we also demonstrated that deceived mayflies can be forced to oviposit into water filled trays, thus their eggs can be collected and transferred back to the creek. We described this phenomenon and a possible solution in a publication [A4].

(5) Ecological trap of *Ephoron virgo*: Each summer huge *Ephoron virgo* mayfly swarms are attracted to lamp-lit areas along the Danube, for example to the bridge of Tahitótfalu. For the human observer it is a beautiful spectacle, but in reality it is an ecological trap killing astronomical numbers of these protected mayflies. In general, due to traffic safety reasons the lamps of bridges cannot be switched off. Our aim was to propose and test a method for preventing the mayfly eggs from being perished on the dry land. We performed two identical field experiments on two tributaries of the Danube (Ipoly and Rába). We used a pair of custom built light sources as beacons for testing whether the female mayflies (arriving to the bridge during their compensatory flight) can be prevented from being attracted to street lights at the bridge. We successfully demonstrated that the ecological trap can be neutralized, thus egg laying females can be prevented from being perished outside the river at light polluted areas. The method uses high-intensity artificial beacon lights attached to the bridge structure and these lights like a “mayfly magnet” keep the swarms above the water. The results has been published [A5, B1, C2, C5, C6, C7, C8, C10, C11, D1, D2].

Furthermore, an exciting nature documentary has been released by T. ZS. M. Produkció and Filmdzsungel Stúdió entitled “Operation Mayfly” (A dunavirág mentőakció) (https://www.youtube.com/watch?v=Kvc9WbzsjD4&t=2625s). In the documentary the ecological trap of *E. virgo* and our solution is discussed. We were happy to participate in this project and to popularize science and the mayfly-threatening ecological problem itself.

Thanks to the positive attitude of the Hungarian Public Road nonprofit PLC, hopefully two permanent mayfly protecting beacons will be installed on the bridge of Tahitótfalu in 2019. The beacons will operate seasonally during swarming periods of *E. virgo*. This configuration will be unique in the world.

(6) Long exposure polarimetry: For cheap measurement of polarization characteristics of our optical environment sequential imaging polarimetry is the best solution. This technique takes polarization pictures through polarizers in succession. However, its main drawback is that during sequential exposure of the polarization pictures, the target must not move, otherwise motion artifacts occur after evaluation of the polarization pictures. In aquatic entomology imaging polarimetry of aquatic habitats and water bodies is important but water surfaces are often undulating. Taking inspiration from photography, our idea was to take the polarization pictures with an exposure that is long enough so that the changes of the moving water surface can be averaged and motion artifacts get reduced. We found that the errors of the measured degree and angle of polarization of light reflected from the undulating water surface decreased with increasing exposure time and converged to very low values. The paper demonstrating the performance of this method has been published [A6].

(7) Ecological trap of *Perla abdominalis*: At Bükkös-creek, besides *E. danica* mayflies we observed, that the asphalt road has negative impact on *Perla abdominalis* stonflies also. Asphalt surfaces are often sources of polarized light pollution and attract aquatic insects, like stonflies. Our aim was to quantitatively measure the proportion of specimens that were deceived and/or killed by the road, which acted as a polarized light polluting object. We found that on average almost 20% of the emerged stoneflies were trapped or killed. The manuscript about these results is under revision [A9].

(8) Attraction of chironomids to dark waters of harbours in lake Balaton: During spring and early summer, the water inside the harbour of Balatonfenyves is significantly darker than the lake itself because of the organic-material-richness of the creek flowing into the harbour. According to our hypothesis, the darker (more polarizing) water surface attracts swarming chironomids, and elicit more oviposition in the harbour and its intimate vicinity. We performed imaging polarimetry and larval samplings on the site and we found that the size and number of larvae were greater in the harbour, which indicated that the conditions for larval development were more favourable in the harbour than in the open water. The manuscript is now under revision [A10].

(9) Polarotactic swarming markers: During the three years, we have conducted both field and laboratory experiments to test whether swarming caddisflies (*Hydropsyche pellucidula*) are attracted by highly polarizing surfaces. According to our hypothesis, strongly polarized objects reflecting light with high degree of polarization can act as swarm markers even if the angle of polarization is not horizontal. On the field we installed the sticky cylindrical, black (strongly polarizing), grey (moderately polarizing) and white (weakly polarizing) test markers. Although we could conduct field experiments and collect some data, the intensity of swarming of *H. pellucidula* was not high enough in the past three years. Hence, we wild-caught caddisfly specimens, we transported them to the laboratory and performed laboratory choice experiments. According to the results, *H. pellucidula* is positively polarotactic to horizontally polarized light, but vertical polarization did not elicit significant attraction. However, a draft of a manuscript has been written, in my opinion, we should continue the work to collect more data, especially on the field.

(10) Underwater polarized light traps: I have built three underwater polarized light traps emitting visible white light with the same spectral composition. The only difference was in the polarization characteristics of the emitted light (100% horizontally polarized, unpolarized and 100% vertically polarized). Sampling with horizontally polarized, unpolarized and vertically polarized traps were performed multiple times at two sites, the sampled zooplankton were identified. Although some organisms (e.g. Copepods) showed interesting behaviour (vertically polarized light was most, unpolarized light was moderately and horizontally polarized light was less attractive), the amount of data is still not enough for a strong publication. We had problems with the traps also, they had to be repaired a few times, which made the work difficult. In conclusion, regarding the results, this part is the weakest in the whole project, but I am going to continue the work.

(11) Electroretinography: Before the three years of this grant I worked three months in University of Neuchatel (Switzerland). My task was to measure the compound eye's spectral sensitivity of various mosquito species with electroretinography (ERG). I have learned the method and carefully observed the professional equipment. Inspired by the ecological trap of *E. virgo* (point 5) I was wondering if the spectral composition of the beacon light could be optimized for the eyes of mayflies if the spectral sensitivity of *E. virgo* could be measured. One of my hobbies is electronics, which I used frequently during my work, mainly in constructing special light sources for the experiments mentioned in this report. During the three years of this grant I have built a group of equipments (e.g. micromanipulators, extracellular amplifier, data acquisition hardware), and now I can measure insect electroretinogram in the 346 nm – 744 nm range with my home-built setup. Besides *E. virgo*, I am going to use the equipment for measurement of spectral sensitivity of several other insect species especially pests.

(12) Distribution of the mysid *Paramysis lacustris*: In a brief survey we revealed the presence of *Paramysis lacustris* in a more than 500-km-long river section spanning from Austria to Croatia. The topic of this paper is not strictly related to the grant.

Fund reallocations between cost categories

During the grant period one fund reallocation was performed (510000 Hungarian Forints) from cost category "miscellaneous" (line 3.3) to "invested assets" (line 4) in compliance with NKFIH. Without conferring with NKFIH I did increased spending (476801 HUF) in cost category "inventory" (line 3.2), because during the grant period it became clear for me that the most important needs of the research are different kinds of components, tools, chemicals and materials for the custom-built experimental equipments. I would like to compensate for the change from cost category lines 2 (461967 HUF remaining) and 3.3 (254505 HUF).

The following list contains a more detailed list about the most significant items that generated the above mentioned increased spending:

Cables and batteries were mainly used for powering the light traps/sources to be used in the field. Servo motors were used in the monochromatic LED light sources for moving filter wheels to reduce light intensities. Butterfly net will be used to collect *E. virgo* mayflies for ERG measurements. Container boxes were used to store and transport experimental equipment to the field. Electronic components were used for building electronic devices for controlling experimental equipment and measuring light intensities, temperature and relative humidity. Various tools were used in the construction of these devices.

Papers in International Peer-Reviewed Journals

[A1] Ádám Egri, Alexandra Farkas, György Kriska, Gábor Horváth (2016) Polarization sensitivity in Collembola: **An experimental study of polarotaxis in the water-surface-inhabiting springtail Podura aquatica.** *Journal of Experimental Biology* 219 (16): 2567-2576 (doi: 10.1242/jeb.139295) (IF: 3.32)

http://real.mtak.hu/48491

[A2] Alexandra Farkas, Dénes Száz, Ádám Egri, András Barta, Ádám Mészáros, Ramón Hegedüs, Gábor Horváth, György Kriska (2016) **Mayflies are least attracted to vertical polarization: A polarotactic reaction helping to avoid unsuitable habitats.** *Physiology and Behavior* 163 (2016): 219-227 + electronic supplement (doi: 10.1016/j.physbeh.2016.05.009) (IF: 2.461)

http://real.mtak.hu/49327

[A3] Dénes Száz, Dávid Mihályi, Alexandra Farkas, Ádám Egri, András Barta, György Kriska, Bruce Robertson, Gábor Horváth (2016) **Polarized light pollution of matte solar panels: Anti-reflective photovoltaics reduce polarized light pollution but benefit only some aquatic insects.** *Journal of Insect Conservation* 20 (4): 663-675 (doi: 10.1007/s10841-016-9897-3) (IF: 1.462)

http://real.mtak.hu/49328

[A4] Ádám Egri, Ádám Pereszlényi, Alexandra Farkas, Gábor Horváth, Károly Penksza, György Kriska (2017) **How can asphalt roads extend the range of in situ polarized light pollution? A complex ecological trap of Ephemera danica and a possible remedy.** *Journal of Insect Behavior* 30 (4): 374-384 (doi: 10.1007/s10905-017-9623-3) (IF: 0.966)

http://real.mtak.hu/65048

[A5] Ádám Egri, Dénes Száz, Alexandra Farkas, Ádám Pereszlényi, Gábor Horváth, György Kriska (2017) **Method to improve the survival of night-swarming mayflies near bridges in areas of distracting light pollution.** *Royal Society Open Science* 4: 171166 (doi: 10.1098/rsos.171166) (IF: 2.504)

http://real.mtak.hu/70629

[A6] Ádám Egri, György Kriska, Gábor Horváth (2018) **Method to reduce motion artifacts of sequential imaging polarimetry: Long enough exposures minimize polarization blurs of wavy water surfaces.** *Applied Optics* 57 (26): 7564-7569 (doi: 10.1364/AO.99.099999) (IF 2017/2018: 1.791)

http://real.mtak.hu/83666

[A7] Péter Borza, Krisztián Kovács, György Alexandra, Júlia Katalin Török, Ádám Egri (2019) **The Ponto-Caspian mysid *Paramysis lacustris* (Czerniavsky, 1882) has colonized the Middle Danube.** *Knowledge & Management of Aquatic Ecosystems* 420 Paper: 2018039, 4 p. (IF 2017/2018: 1.525)

http://real.mtak.hu/89918

[A8] Ádám Egri, Kriska György – **How does the water springtail optically locate proper habitats? Spectral sensitivity of photo- and polarotaxis in *Podura aquatica*.** *Journal of Experimental Biology* (**under revision**)

[A9] Ádám Egri, Dénes Száz, Ádám Pereszlényi, Balázs Bernáth, György Kriska – **Quantifying the polarized light pollution of an asphalt road: an ecological trap for the stonefly, *Perla abdominalis* (Guérin-Méneville, 1838) (Plecoptera: Perlidae).** *Aquatic insects* (**under revision**)

[A10] Ádám Pereszlényi, Ádám Egri, József Szekeres, Dénes Száz, Gábor Horváth, György Kriska – **First evidence for ecological advantage of polarized light pollution: positive effect of a dark lake patch at a canal inflow on chironomids.** *Freshwater Biology* (**under revision**)

Popular Science Articles

[B1] Farkas Alexandra, Egri Ádám, Horváth Gábor, Kriska György (2016) **Dunavirág-kutatás: Életmentő fénycsapdák.** *Élet és Tudomány* 71 (34): 1074-1076 + címlap

https://arago.elte.hu/sites/default/files/EletmentoFenycsapdak_ET.pdf

[B2] Egri Ádám (2017) **Látás kezdetleges, ám leleményes módon: A világ ugróvillás szemmel.** *Élet és Tudomány* 72 (2): 50-52

https://arago.elte.hu/sites/default/files/Podura-aquatica_ET.pdf

Lectures

[C1] Egri Á. (2016) **Polarizációs bögölycsapdák bemutatása, valamint repülő rovarok távérzékelésének lehetőségei** (Invited lecture). *Magyar Rovartani Társaság 836. előadóülése* - 2016. március 18. péntek 16 óra, Budapesti Corvinus Egyetem Kertészettudományi Kar E/2 Budapest XI. Ménesi út 43–45.

[C2] Egri, Á., Farkas, A., Horváth, G., Kriska, GY. (2016) **A dunavirágot érintő összetett ökológiai csapdák kivilágított hidaknál** (Lecture). *Vonalas létesítmények és élővilág: Kapcsolatok, megoldások, monitoring.* 2016. május 4., szerda, Fővárosi Állat- és Növénykert Barlangterme (1146 Budapest, Állatkerti körút 6-12.). Program és összefoglalók 19-20. oldal

[C3] Egri, Á., Farkas, A., Horváth, G., Kriska, Gy. (2016) **Polarization sensitivity in the water-surface-inhabiting springtail, *Podura aquatica*** (Lecture). *2nd Central European Symposium for Aquatic Macroinvertebrate Research*, 3–8 July 2016, Pécs, Hungary

[C4] Egri Á., Kriska Gy. (2016) **Ugróvillások láthatatlan világa.** (Educational lecture) *Kutatóhelyek tárt kapukkal.* Magyar Tudományos Akadémia, Duna-kutató Intézet, Budapest, 2016. november 22.

[C5] Farkas Alexandra, Potyó Imre, Egri Ádám (2016) **A dunavirág fénycsapdája: Környezetoptikai vizsgálatok és természetfotók.** (Invited lecture) 2016. november 29. Szegedi Tudományegyetem, Ökológiai Tanszék, Szeged

[C6] Száz Dénes, Egri Ádám, Farkas Alexandra, Pereszlényi Ádám, Kriska György (2017) **A dunavirág éjszakai tömegrajzását érintő összetett ökológiai csapda és hatásának csökkentése fénysorompóval** (Lecture). *Országos Környezetvédelmi Értekezlet*, Magyar Közút Nonprofit Zrt., Balatonföldvár, 2017. október 9.

[C7] Egri Ádám, Kriska György (2018) **Kérészvédő fénysorompó a dunavirágot fenyegető mesterséges ökológiai csapda kiküszöbölésére** (Lecture). *Vonalas létesítmények és élővilág: Kapcsolatok, megoldások, monitoring. IV. Vonalas létesítmények IENE Műhelytalálkozó* – TRANSGREEN WG találkozó. 2018. május 16., szerda, Fővárosi Állat- és Növénykert Barlangterme (1146 Budapest, Állatkerti körút 6-12.). Program és összefoglalók 20. oldal .

[C8] Egri Ádám, Horváth Gábor, Kriska György (2018) **Fénysorompó a védett dunavirág (*Ephoron virgo*) kérészfaj védelmére** (Lecture). *Urbanizációs Ökológia Konferencia*, Veszprém. 2018. október 19-20. Absztraktfüzet 19. oldal.

[C9] Egri Ádám (2018) **A vízi ugróvillás (*Podura aquatica*) polarizáció-érzékelése** (Lecture). *Magyar Biofizikai Társaság – Fotobiológiai Miniszimpózium*, Budapest, ELTE Lágymányosi campus, 2018. október 31. Program és összefoglalók 8. oldal.

[C10] Dénes Száz, Ádám Egri, Alexandra Farkas, György Kriska, Gábor Horváth (2018) **Dual ecological trap of the night-swarming mayfly *Ephoron virgo* at lamp-lit bridges in Europe** (Lecture), *5th International Conference On Artificial Light At Night*, Snowbird, Utah, USA, 2018. november 12-14.

[C11] Dénes Száz, Ádám Egri, György Kriska, Gábor Horváth (2018) **Reducing the effect of dual ecological traps on night-swarming mayflies at lamp-lit bridges** (Lecture), *Symposium on promotion and protection of the night sky*, Capraia Island, Olaszország, 2018. szeptember 13-14.

[C12] Egri Ádám (2018) **Vizes élőhelyek rovarszemmel** (Educational lecture), *MTA - Street science - Víznap*, 2018. június 1., 12:40-13:10, Budapest, MTA Székház

Poster

[D1] Egri Á., Farkas A., Száz D., Tarjányi, N., Horváth, G., Kriska, Gy. (2016) **Ecological traps near Danube bridges for the night-swarming mayfly, *Ephoron virgo*** (poster). *41st international IAD conference*, 13-16 September 2016, Sibiu

[D2] Dénes Száz, Ádám Egri, Alexandra Farkas, György Kriska, Gábor Horváth (2018) **Dual ecological trap of the night-swarming mayfly *Ephoron virgo* at lamp-lit bridges in Europe** (Poster), *5th International Conference On Artificial Light At Night*, Snowbird, Utah, USA, 2018. november 12-14.